A New 2x2 Microstrip Patch Sub-array for 60GHz Wideband Planar Antenna with Ridge Gap Waveguide Distribution Layer

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***Abstract*— We propose a two layer planar antenna where a ridge gap waveguide corporate distribution network feeds a subarray of 2×2 radiating microstrip patch elements. There exists a coupling slot in the ground plane of the substrate layer which allows the excitation of the microstrip patch elements from the ridge gap waveguide layer. The ground plane of the substrate also serves the purpose of top metal layer for the ridge gap waveguide section. The proposed antenna is operating over 15% relative bandwidth covering 56-66 GHz frequency range with -12 dB reflection coefficient. The simulated directivity of the 2×2 element array is 11.5dbi at the center of the band. The simulated directivity for the 16×16 element array using the infinite array approach is found to be 28.7dBi.**

Index Terms— ***Single-layer structure, microstrip patch array, waveguide slot-array, corporate feed network, gap waveguides.***

I. INTRODUCTION

High efficiency planar antennas are becoming very essential components for compact and cost-effective mmWave systems. Waveguide slot array antennas are expected to provide high efficiency and high gain even at mm-Wave frequency range due to lower losses in antenna feed networks [1, 2] Waveguide slot array antennas can be series-fed type or parallel-fed type. Series-fed slot array antennas have simple geometry but suffer from narrow operational bandwidth due to long-line effect [3, 4]. On the other hand, cavity-backed slot sub-arrays with an underlying corporate feed network will have both higher efficiency and wider bandwidth. Antennas around 80% efficiency and 7-10% relative bandwidth have been described in [5, 6]. However, the key challenges with such multi-layer antenna structure are high fabrication cost and manufacturing complexity to achieve good electrical contacts among the feed layer, cavity layer and radiating slot layer.

To overcome this problem of good electrical contact associated with mechanical assembly, the gap waveguide technology can be employed. The gap waveguide technology presented in [7, 8] uses the cut-off of a PEC-PMC parallel-plate waveguide configuration to control desired electromagnetic propagation between the two parallel plates without the requirement of electrical contact. This is quite advantageous for the mechanical assembling of mmWave antennas when tolerance in fabrication process becomes a key factor at such high frequencies. Also, the Q-factor analysis confirms that the losses in ridge gap waveguide and groove gap waveguide structures are comparable to that of standard rectangular waveguide [9]. Therefore, the feed network losses will be quite low for gap waveguide antennas. Also the gap waveguide technology is very suitable for RF packaging [10-12], which plays an important role in integrating RF electronics with the antenna.

The first gap waveguide array antennas were realized around 10-15 GHz in ridge gap waveguide [13] and inverted microstrip gap waveguide technology [14]. The first mmWave gap waveguide antenna was the microstrip-ridge gap antenna described in [15]. The latter turned out to have more losses than expected and to be expensive to manufacture due to the cost of the low-loss soft substrate and the large number of via holes needed, and there were problems with grating lobes as well. Therefore, we present here a solution without substrate in the distribution network. The proposed new solution is a double layer wideband 2×2 microstrip patch-array antenna excited by ridge gap waveguide, thus not depending on any substrate in the feed layer. The spacing between the patches at the top radiating layer is 3.0mm, corresponding to about 0.66λ at the highest operating frequency of 66GHz. Thus, the problems associated with grating lobes will be much smaller than for the antenna in [15] having slot spacing of 0.88λ.

II. ANTENNA STRUCTURE

The structure of the proposed planar ridge gap waveguide antenna is shown in fig.1. The antenna structure consists of a ridge gap waveguide feed layer at the bottom. This distribution layer can easily be expanded to a bigger corporate feed network with power dividers or T-junctions. The feeding ridge gap waveguide excites the coupling slot etched in the ground plane of the above-located microstrip substrate. The coupling slot is placed at the center of the radiating patch layer. The four radiating patches are placed on the top of the substrate and are equally spaced from the coupling slot. Thus these four slots are excited equally in amplitude and phase to give a broadside beam. The pin dimensions in ridge gap waveguide feed layer are designed to achieve a parallel-plate stopband from 50-75GHz. The pins have the dimension of $0.6\times0.6\times1.25\text{mm}^3$. The period of pins used in this design is 0.75mm. There is an air gap of 0.25mm between the ground of the substrate and the bottom ridge gap waveguide section. The dimensions of the radiating patches are chosen to be $1.75\times1.4\ \text{mm}^2$. The substrate used in the radiation layer is Rogers R3003 with a thickness of 0.254 mm. The width and length of the coupling slots are also chosen to be 0.50mm and 2.5 mm respectively.

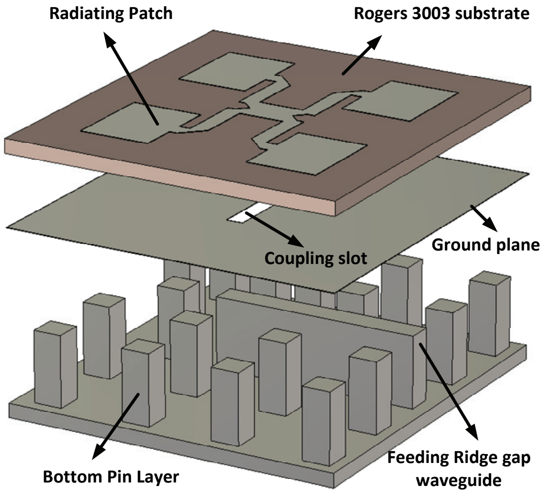

Fig. 1: Perspective view of 2×2 double-layer planar array

III. MATCHING BANDWIDTH AND RADIATION PATTERNS

In numerical simulation, the 2×2 patch-array fed by ridge gap waveguide antenna is excited with a waveguide port at the ridge gap waveguide feed line. Simulated reflection coefficient at the feed waveguide port is shown in fig.2. The simulated bandwidth for -12dB reflection coefficient is 56-66 GHz, corresponding to 16%. The results are very similar for an isolated sub-array (results shown) and a sub-array in an infinite array environment.

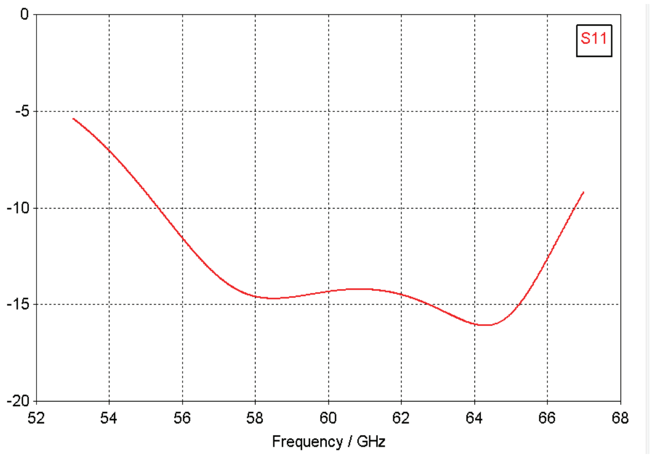

Fig.2 Simulated S_{11} of the 2×2 single-layer ridge gap waveguide array antenna.

Simulated far-field patterns in the operating bandwidth at 58-67GHz are also presented in fig.3 (a) and fig. 3(b). As expected, we find that the E-plane patterns are wider than the H-plane patterns. The simulated directivity of this 2×2 slot-array antenna is found to be around 11.5 dBi at the center of the band. The simulated radiation patterns for 16×16 element array using the infinite array approach with periodic boundary are shown in fig. 4(a) and fig. 4(b).

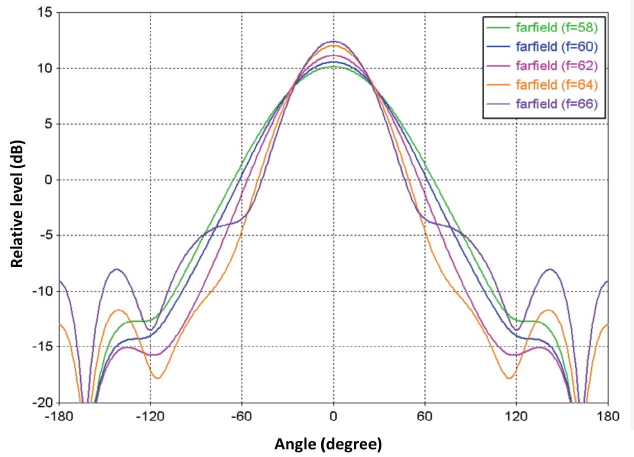

Fig.3 (a) Simulated E-plane patterns for the 2×2 element array antenna.

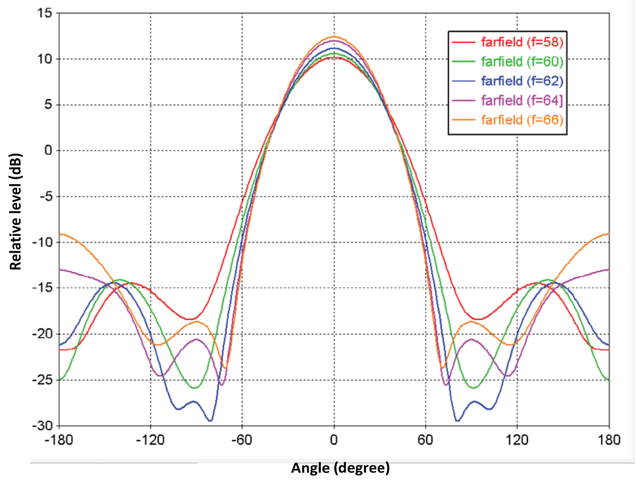

Fig.3 (b) Simulated H-plane patterns for the 2×2- element array antenna.

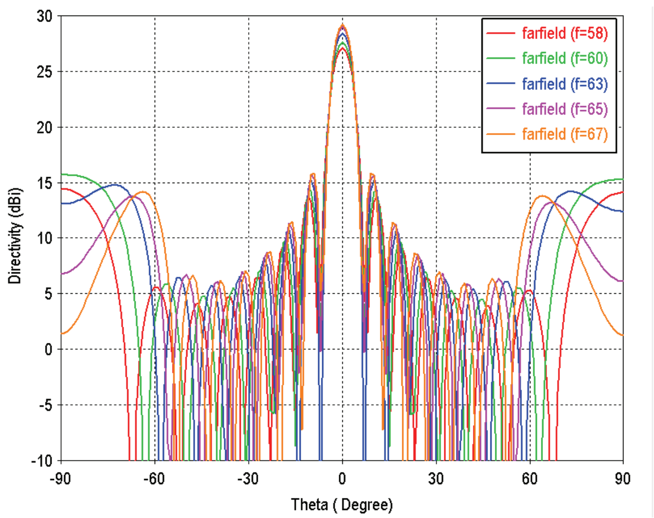

Fig.4 (a) Simulated E-plane patterns for the 16×16 element array antenna.

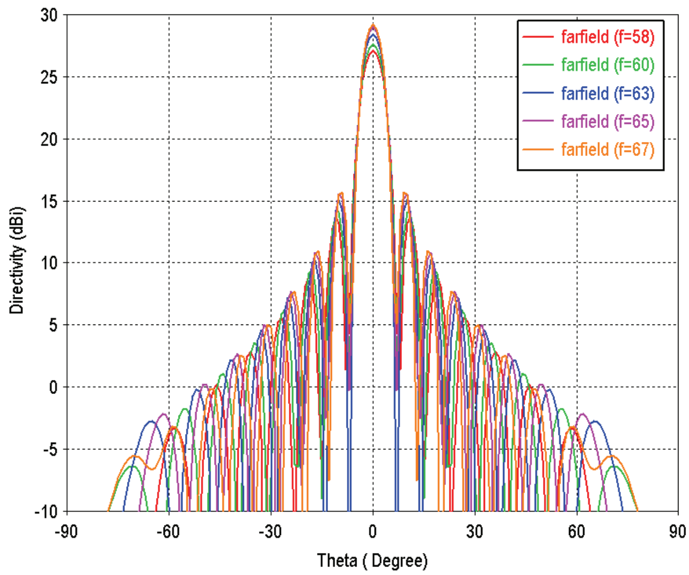

Fig.4 (b) Simulated H-plane patterns for the 16×16- element array antenna.

IV RIDGE GAP WAVEGUIDE FEEDING NETWORK

The ridge gap waveguide feeding network is based on the basic 3-dB power divider or T-junction proposed in [16]. The ridge gap waveguide based four-way power divider is built using the same T-junction and the schematic of this four-way power divider is shown in fig.5. The simulated results for this four-way power divider is shown in fig.6. The simulated results show that even for such a compact four-way power divider, it is possible to have good S_{11} and a very small amplitude imbalance between the S_{21}, S_{31}, S_{41} and S_{51} on the four output ports. Thus this four-way power can be used as a building block for a bigger corporate feeding network based on ridge gap waveguide.

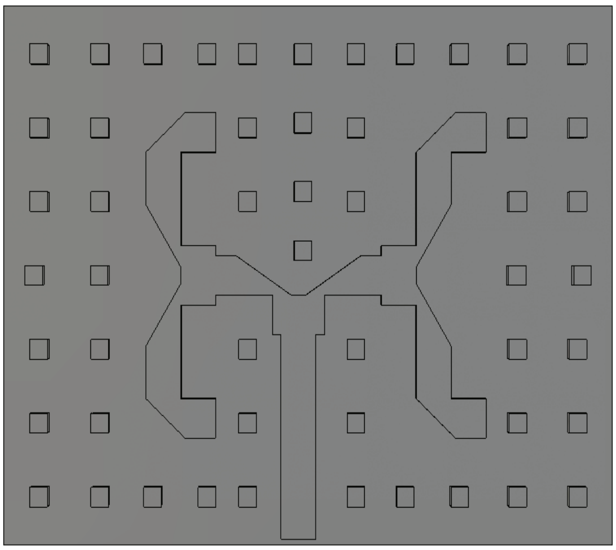

Fig.5 Schematic of the 4-way power divider based on ridge gap waveguide technology; the top metal lid is not shown.

IV CONCLUSION

We present a mechanically versatile 2×2 sub-array for a large planar array antenna design based on ridge gap waveguide technology. Simulated results show promising results with large impedance bandwidth and good radiation pattern. Also a 16×16 element array has been simulated using infinite array approach. The radiation patterns have high -13dB sidelobes around 60° in the E-plane, but in the H-plane the sidelobes are very low and satisfies ETSI class 2 and 3. The impedance bandwidth of the antenna also covers the whole license free band from 57 to 66GHz. The unit cell is small, so a full 16x16 array will be smaller and have 2.5 dB lower directivity than using larger unit cells like that in [15]. The proposed antenna could be a good candidate for 60GHz applications filling the need for directivities between $2^n \times 2^n$ and $2^{n+1} \times 2^{n+1}$ arrays with larger unit cells.

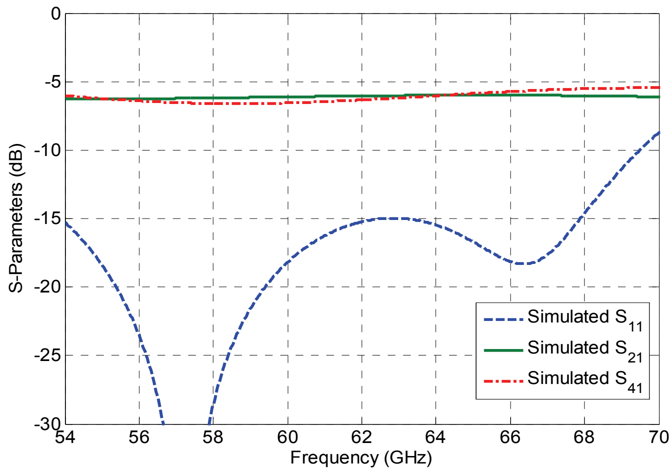

Fig.6 Simulated S-parameter results for the 4-way power divider in ridge gap waveguide.

Acknowledgment

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